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A New Compact Rotary Compressor: Coupled Vane Compressor

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ABSTRACT

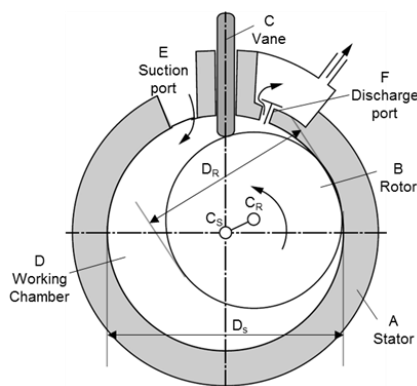
According to JARN 2017, the annual production for positive displacement rotary compressors alone exceeds 154.3 million pieces and growing at 11.2% annually ("World Compressor Market," 2017). Obviously, a lot of materials, especially metal, are being used every year just to produce compressors alone. In the interest of saving these materials, and hence bring towards a more sustainable environment, in this paper, a new rotary vane compressor which is probably the world's most compact rotary compressor has been introduced. It is called Coupled Vane Compressor for the reason that the two vanes are coupled together. The unique feature is that the two coupled vanes cut through the rotor. Hence theoretically, any size of the rotor that is as big as the shaft of the motor will work with this compressor design. Due to its compactness, it is believed that, this design has the potential in saving a significant amount of materials, especially metal, in producing compressor for various applications including cooling, heating, refrigeration and air compression. In this paper, the basic design of this compressor will be presented. Mathematical model has been formulated and its working principle will be shown and illustrated.

1. INTRODUCTION

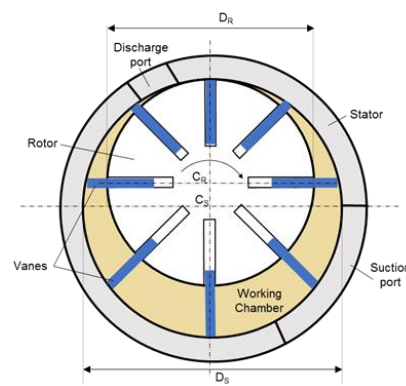
There are many types of positive displacement rotary vane compressor currently used in air-conditioning, refrigeration and air-compression industries. In refrigeration and air-conditioning applications, the rolling piston compressor and its various variants are the most widely used. Figure 1 shows the basic features of rolling piston compressor, and other available rotary vane compressors such as sliding vane, spool and revolving vane.

From Figure 1, it is clearly shown that all the existing rotary compressors have one feature in common and that is a relatively large rotor. In all the rotary compressor design, the ratio of rotor radius to cylinder radius is generally more than 3/4. That is to say that the rotor occupies a significantly large space of the cylinder, which otherwise can be used as the useful working chamber space.

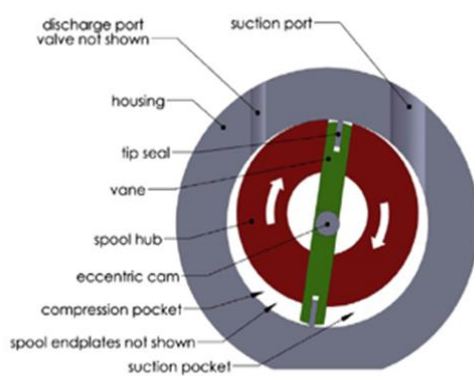
The reasons for existing rotary compressors to have such a relatively large rotor is due to their respective design and hence the need for them to work properly. This paper presents a new rotary compressor which reduces the relative size of the rotor significantly, this new design is called coupled vane compressor. Its design, operational principle, and potential advantages will be discussed and presented in this paper.



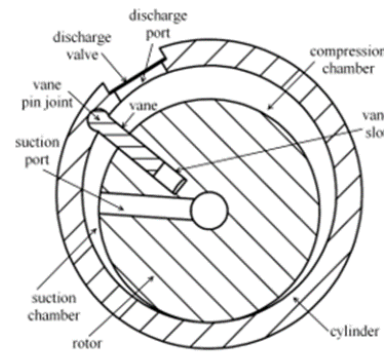
Rolling piston compressor (Soedel, 2010)



Sliding vane compressor (Tramschek & Ooi, 1992)



Rotary spool compressor (Bradshaw & Groll, 2013)



Revolving vane compressor (Teh & Ooi, 2009)

Figure 1: Rotary compressors with their relatively large rotor relative to the cylinder

2. DESIGN AND THE WORKING PRINCIPLE

2.1 Design of the new rotary compressor

Figure 2 shows the schematic of a coupled vane compressor. In its basic form, it has a stator, a rotor and a pair of vanes. The rotor is housed inside the stator along the sealing arc. The sealing arc is a depression in the shape of a circular arc, the radius of which is equal to the radius of the rotor + δ , where δ is the clearance. The rotor includes the diametric slot in which the vanes can slide through. The vanes have a dovetail feature on their forward planar face which allows them to slide on each other, and also act as gripping mechanism. The rotor rotates in a fixed axis which causes the vanes to rotate and also slide diametrically through the rotor and radially outward such that the tips of the two vanes are constantly in contact with the inner surface of the stator. During the operation, The vane-tip-stator contact is made possible by the fluid pressure and the centrifugal force from the rotation. Consequently, the working chambers are formed between the stator, rotor and the vanes. The volume of these working chambers vary during the operation, and results in suction, compression and discharge of the working fluid. Most importantly, and uniquely, as opposed to all the existing rotary compressors mentioned, the rotor diameter can be significantly small relative to the diameter of the stator, for the effective operation of the compressor. This also implies that for a fixed displacement volume of the compressor, the diameter of the rotor of the coupled vane compressor can be designed to be smaller and hence allows the diameter of the stator to get proportionally smaller too. This design has resulted in one of the most compact rotary compressor designs.

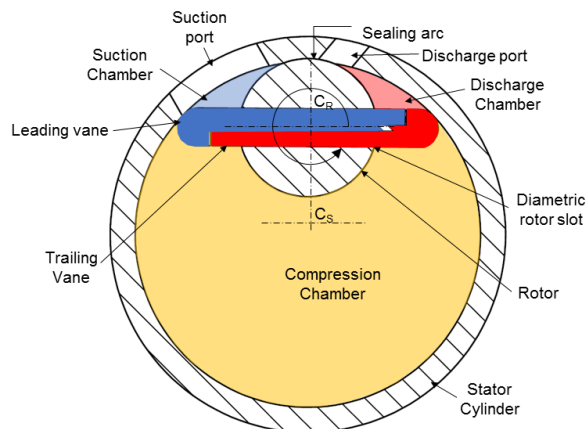


Figure 2: Schematic of a coupled vane compressor

2.2 Working principle

At the start of the working cycle of the coupled vane compressor, the vanes are assumed to align at the vertical axis containing the rotor centre C_R and the stator cylinder centre C_S . As the rotor rotates in the anticlockwise direction, the leading vane tip housed inside the rotor slot protrudes out. As it does so, the suction chamber is formed between the backward face of the leading vane, rotor and the stator wall. Following the rotation of the rotor, the volume of this suction chamber increases and the working fluid is induced into the suction chamber from the suction plenum. The suction process is illustrated in steps 1 to 5 in Figure 3. The suction process continues until 270° of rotation, after which, the tip of the trailing vane seals off the suction port and the suction chamber becomes the compression chamber. Following the rotation, the volume of this compression chamber decreases and the pressure of the working fluid increases. The compression process is shown in steps 5-6 in Figure 3. As shown in step 6 in Figure 3, the leading vane tip then exposes the discharge port to the compression chamber. Meanwhile, the pressure in the compression chamber continues to rise until it is greater than the discharge pressure. Once, the pressure in the compression chamber becomes greater than the discharge pressure, the compressed fluid is discharged out of discharge port by the opening of the reed valve. The discharge process is completed after the tip of the trailing vane seals off the discharge port. In this way, the working cycle of the coupled vane compressor is completed in 540° revolutions.

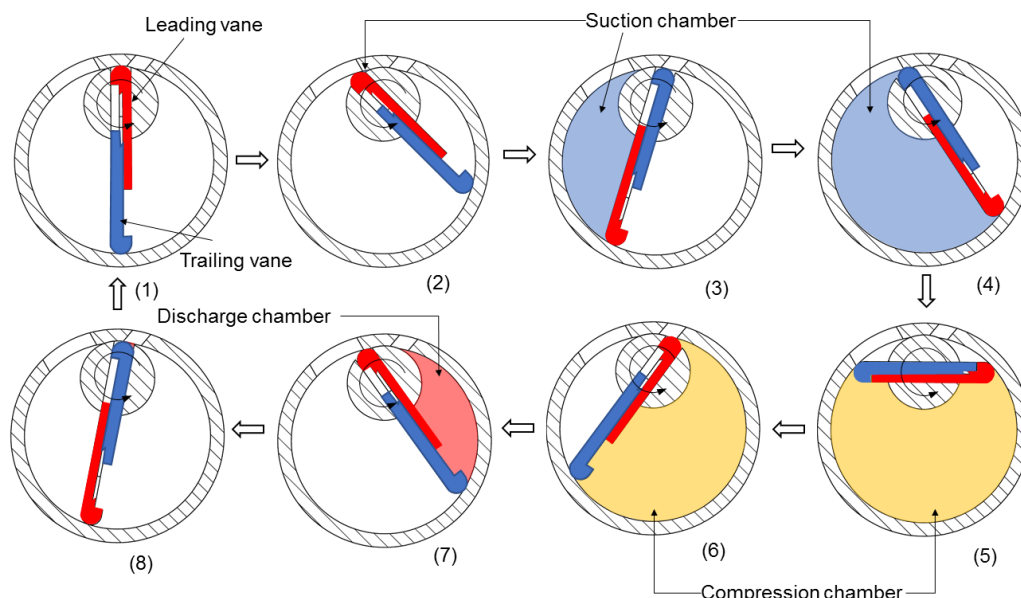


Figure 3: Working principle of coupled vane compressor

3. DESIGN CONSIDERATION

In this section, we compare the volume of material required to manufacture a rolling piston and coupled vane compressor. For the comparison, the internal diameter of the stator, D_s , the height of the compressor, h , and the thickness of the stator wall, t , are kept constant. The typical values assumed for these parameters are shown in Table 3.1 and these parameters are illustrated in Figure 4. The rotor-to-stator diameter ratio designed for coupled vane compressor is 0.4. The rotor-to-stator diameter ratio for the rolling piston compressor is varied between 0.6 to 0.8 and the total volume of material required for each ratio is calculated. This total volume of material required is calculated by adding the volume of stator including the wall thickness and the volume of the rotor. Then, for each rotor-to-stator ratio, the corresponding volume of the working chamber is calculated by subtracting the rotor volume from internal volume of the stator. To compare the volume of rolling piston compressor with the coupled vane compressor, the volume of the working chamber of both the compressors are kept same. This implies, corresponding to this working chamber volume, the diameter of the coupled vane compressor can then be calculated. This diameter can then be used to calculate the corresponding total volume of material required for the coupled vane compressor. Finally, the total volume of material required for the coupled vane compressor can be compared with the total volume of material required for the rolling piston compressor to determine the amount of material being saved using the coupled vane compressor.

Table 3.1: List of parameters and their typical values

D_s	50 mm
h	30 mm
t	8 mm

As the rotor-to-stator diameter ratio for the rolling piston is increased, the corresponding volume of the working chamber within its stator will decrease. This meant the diameter of the stator of the coupled vane compressor will proportionally decrease. The result of this study is shown in Figure 5. Generally, the rolling piston compressor has the rotor-to-stator diameter ratio between 0.65 to 0.75. For this range of ratio, the corresponding percentage of volume of material saved by using coupled vane compressor was calculated to be around 34-50%. Additionally, the volume of material required for the compressor housing will depend on the volume of the stator. This implies if the volume of material required to fabricate the compressor housing is incorporated into the calculation, this percentage of material saving will be even larger.

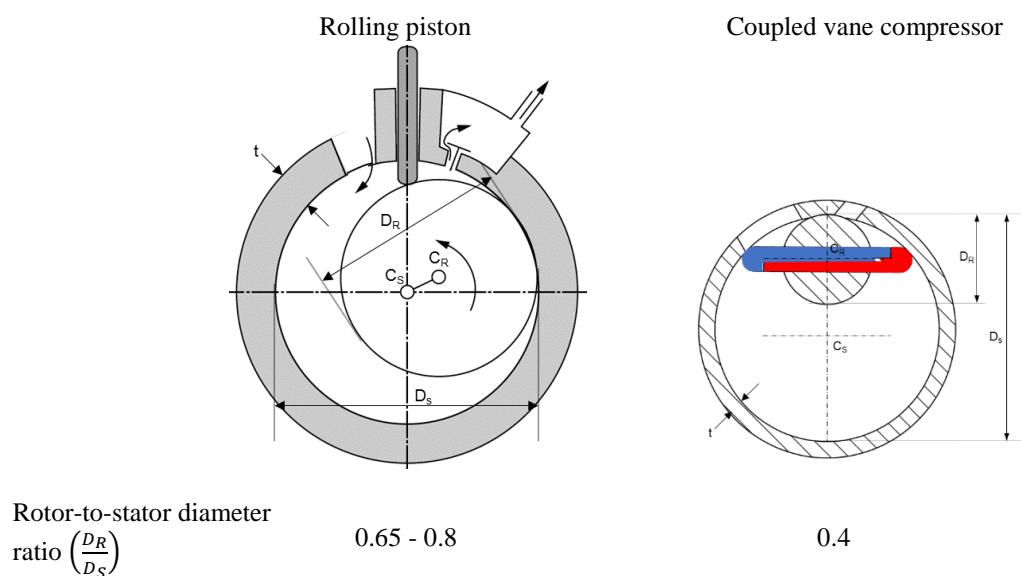


Figure 4: Comparison between rolling piston and coupled vane compressor

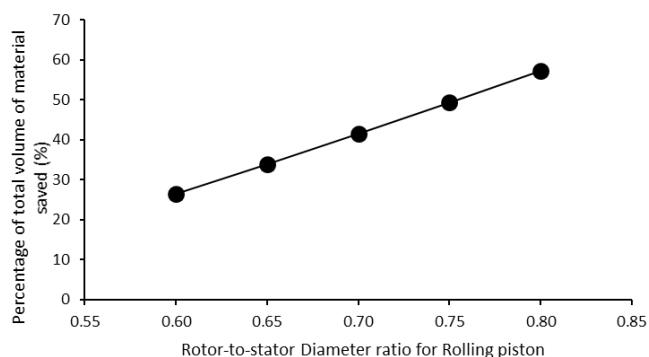


Figure 5: Variation of the percentage of total volume of material saved using coupled vane compressor

4. SOME SIMUALTION RESULTS

A lumped parameter mathematical model has been formulated based on the geometry of this new compressor. Figure 6(a) shows the variation of the working chamber volume for an arbitrary size of a compressor. Due to its unique design and division of the working chamber by two diagonally opposed vanes design, as shown in Figure 2, it is noted that one working cycle takes 540° of rotation to complete.

Air was selected as the working fluid. The suction pressure of 100 kPa and the discharge pressure of 500 kPa was assumed. The variations of working fluid pressure, pressure volume diagram and instantaneous power are shown in (b), (c) and (d) of Figure 6.

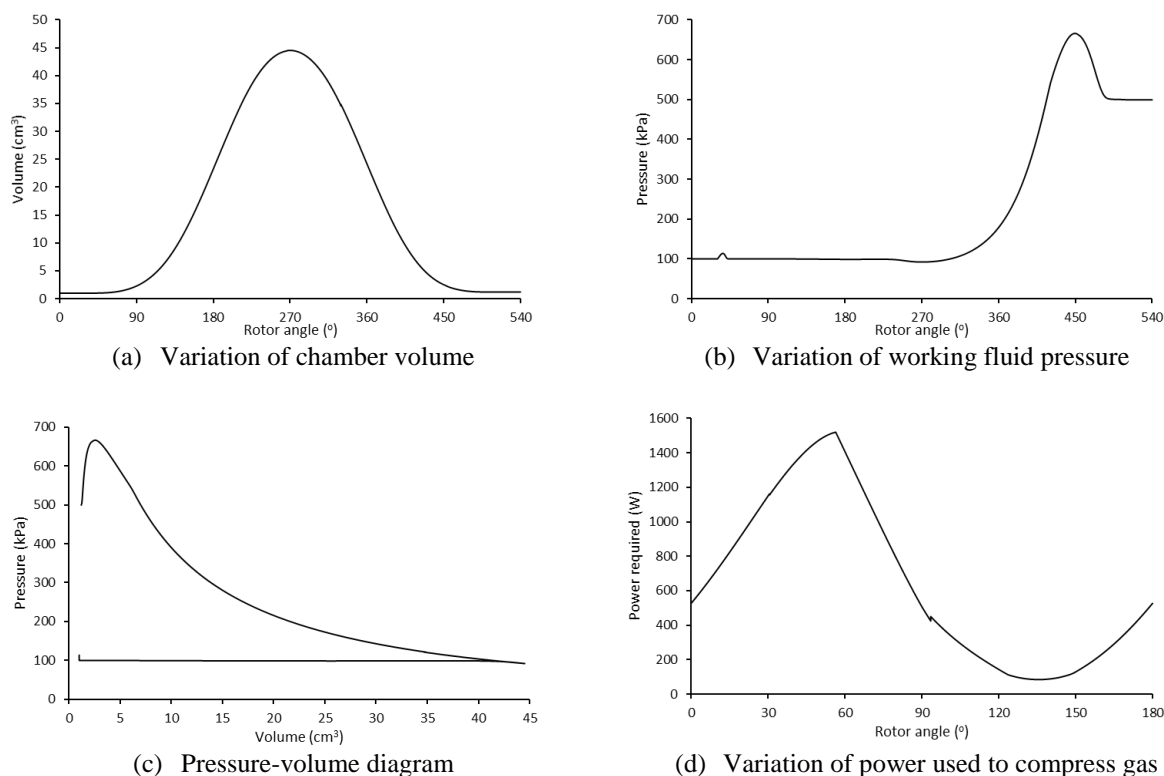


Figure 6: Some typical variation of predictions from a numerical model

5. CONCLUSIONS

A new positive displacement rotary vane compressor namely Coupled Vane Compressor has been introduced. As compared to all the existing rotary vane compressors, this new compressor has a great potential in saving significant amount of materials used in its production. This is achieved with its unique feature where its rotor is significantly smaller relative to the size of the cylinder than all the rotary vane compressors available today. It is therefore most probably the most compact rotary vane compressor design available today. It uses a simple rotary mechanism which has been proven to work in other rotary vane compressors and its construction is relatively simple. It is hoped that, in the near future, this new, very compact rotary vane compressor design will help in saving significant material usage in producing rotary vane compressors for cooling, heat and refrigeration industries, and thus pointing towards a more sustainable environment for all.

NOMENCLATURE

h	height	(m)
t	thickness	(m)
C	centre	(-)
D	diameter	(m)
δ	radial clearance	(μm)

Subscript

R	rotor
S	stator

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